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ABSTRACT

The validity (accuracy and precision) of using scales to assess the age of northern pike *Esox lucius* in the Arctic-Yukon-Kuskokwim region of Alaska was studied. Annuli counts among scales, vertebrae and cleithra were compared for three readers. A single reader was used to compare the precision of scale readings between three different populations. Mark-recapture data from five populations in the AYK region of Alaska was used to examine the accuracy of readings from scales in determining the age of northern pike. For northern pike less than 450 millimeters of fork length, scales were the most precise structure (92% agreement between two readings). For fish greater than 450 millimeters of fork length, cleithra had the highest precision (52%) and scales were second highest (39%). No difference was found in the average error among structures ($P = 0.45$). The increase in the number of scale-annulus increments agreed with the time elapsed between captures 32% of the time.

KEY WORDS: northern pike, *Esox lucius*, scales, cleithra, vertebrae, age validation.

INTRODUCTION

Background

Northern pike *Esox lucius* are popular with sport anglers in the Arctic-Yukon-Kuskokwim (AYK) region of Alaska. According to current estimates of recreational fisheries harvest in the AYK region (from 1977 through 1990), northern pike rank fourth for all species (Mills 1991). Harvest estimates of northern pike in the AYK region averaged 15,338 fish between 1977 and 1990 ranging from 11,661 to 19,624; 12,330 northern pike were harvested in 1990 (Mills 1991). Anglers in the AYK region have accounted for 75% to 97% of the statewide harvest of northern pike on an annual basis, with waters of the Tanana River drainage accounting for about 64% of the regional harvest. Minto Flats, and Volkmar, George, and Harding lakes are among the most popular fishing areas for northern pike in the Tanana River drainage. T Lake receives a relatively low level of fishing effort.

Stock assessment of northern pike and creel surveys of recreational fisheries for them in the Tanana River drainage were conducted from 1971 to 1984 (Cheney 1972, Peckham 1972-1985). Research conducted at Volkmar Lake in 1985 (Peckham 1986) provided the first estimates of northern pike abundance and sex and age composition in Alaska. Research conducted from 1986 through 1991 has provided additional estimates of abundance, along with information on catch-per-unit of sampling effort (CPUE), catchability, sampling methods, and life history of northern pike in Minto Flats and Harding Lake (Burkholder 1990, 1991a, 1991b) and in Volkmar, George, and T lakes (Peckham and Bernard 1987, Clark et al. 1988, Clark 1988, Clark and Gregory 1988, Timmons and Pearse 1989, Pearse 1990, 1991).

During the above investigations, information on age of individual northern pike was obtained for use in stock assessment. To date, age-size data have been used to describe age related growth (for example length and weight-at-age), time-specific cohort abundance, and estimated survival and recruitment rates of selected cohorts between sampling events.

Published studies validating assigned ages in northern pike through annular marks detected in various body structures include Williams (1955, scales), Frost and Kipling (1959, scales and opercular bones), Casselman (1967, scales; 1974, scales and cleithra; 1978, scales and cleithra; 1979, cleithra; 1983, scales and cleithra), Babaluk and Craig (1990, cleithra and pelvic fin rays), and Laine et al. (1991, scales and cleithra). Other authors (Beamish and Fournier 1981; and Beamish and McFarlane 1983, 1987), while not speaking directly to northern pike, have detailed analytical methods and called for validation of assigned ages to prove accuracy and ensure confidence in resultant data reflecting population dynamics. They suggest validating annular marks in age structures using either mark-recapture studies, or through the recapture of fish of known age. Of the studies directly assessing age validation of northern pike, five authors validated their techniques through either the use of mark-recapture experiments with tags (Frost and Kipling 1959, Casselman 1967, and Laine et al. 1991), or through injection of oxytetracycline (Babaluk and Craig 1990, Casselman 1974, and Laine et al. 1991).

Over the past years, AYK staff have attempted several studies to answer questions regarding precision and accuracy in our methods of determining age of northern pike. Annuli counts among scales, vertebrae and cleithra were compared between readers in 1986 (Peckham and Bernard 1987). In 1989, repeatability of assigned ages was examined. Precision in ages from scales was determined between trials for one reader, among two scales taken from the same fish, and across several populations (unpublished data).

Study Goals and Objectives

The overall goal of this report is to summarize information on the precision and accuracy of determining the age of northern pike collected to date into one document. This document is a summary of: (1) findings in the literature; (2) past studies on precision in age determination which have been conducted by AYK staff that have not been completely reported; and, (3) results of age validation using mark-recapture information from databases for populations in T, Volkmar, George and Harding lakes, and Minto Flats. The specific objectives of the age validation study are to:

1. estimate the proportion of recaptured northern pike in the database whose assigned ages reflect the time elapsed between captures; and

2. estimate the magnitude of any bias in age determination of northern pike.

METHODS

General Methods

Annual sampling of northern pike has been part of AYK research since 1985 in Volkmar Lake, since 1986 in T Lake, since 1987 in George Lake and Minto Flats and since 1990 in Harding Lake. During all sampling events, all captured northern pike greater than 299 mm (including fish recaptured within-season) were measured to the nearest mm of fork length (FL). All fish were examined for tags and evidence of secondary marks. Untagged northern pike judged to be in a healthy condition were marked and released. Each fish was marked twice with a Floy FD-68 internal anchor tag inserted posteriorly at the left base of the dorsal fin and with a fin clip or opercle punch unique to that sampling event. When possible, the sex of each live fish was determined by the presence of sex products or by external characteristics as described in Casselman (1974). Fish for which sex could not be determined were recorded as neither male nor female. All data was recorded on a form designed to be optically scanned for fast entry of data.

A smear of scales (consisting of at least three) was taken from the preferred zone adjacent to, but not on, the lateral line above the pelvic fins as described by Williams (1955). Scales were placed in individual coin envelopes marked with the appropriate litho-code from the form and sample number. Scales were removed from coin envelopes in the laboratory, cleaned, and two non-regenerated scales per fish were mounted on gummed cards. Scales were determined to be regenerated when concentric growth rings (circuli) on the external bony layer of the scale, normally present and associated with scale (and body) growth in northern pike, were absent and had been replaced by etched, opaque, non-circuli growth in a portion of the central scale area (Williams 1955). These scales were rejected as indicators of age because the time and amount of previous scale growth, plus that required for regeneration, is uncertain. The cards were used to make scale impressions on 20 mil acetate sheets using a Carver press at 137,895 kPa (20,000 psi) heated to 93 C for one minute. Scales were read on a microfiche reader (32x) and ages recorded in accordance with criteria for recognizing annuli established by Williams (1955), Frost and Kipling (1959), and Casselman (1967): annuli on the anterior part of the scale were identified when one or two fragmented or irregular circuli (caused by growth interruption) occurred among or at the anterior scale edge of a group of relatively narrowly spaced circuli. This fragmentation produces a disrupted look to the scale's anterior, while at the same time creating a clear line on the scale's dorsal and ventral margins which cuts over into the adjoining circuli. These give a 'check' or annular mark to those portions of the scale. This was considered to be a true annulus (as opposed to a pseudoannulus or false check), if the clear line and associated 'cutting over' of adjoining circuli continued around the scale's posterior. As the clear line can almost completely continue around the scale in a pseudoannulus (but rarely compared with a true annulus), potentially false annuli were eliminated by close examination and counting the number of circuli adjacent to the annulus (Williams 1955). If the number of anterior circuli to either the scale margin or next annulus was more than twice the number of posterior circuli, then the mark was considered to be a pseudoannulus. If less than twice, the mark was accepted as a true annulus per Williams (1955) and Frost and Kipling (1959).

Annulus (and pseudoannulus) formation in northern pike scales are 'generally' characterized by an interruption in the successive, orderly development of scale circuli. This is presumably due to the effects of both biological and environmental factors upon the mineralization (primarily calcium) of the dermal skeleton (scales). Casselman (1967) determined that in immature northern pike, temperature was the most important factor controlling linear growth and annulus formation. Whereas in mature fish, annulus formation represented a combination of growth interruption (and hence formation of orderly scale circuli) related to several factors, among which were decreasing water temperature, accumulation of reproductive products, and an interruption in the resumption of growth caused by spawning. Pseudoannulus formation was tentatively linked to "a number of intrinsic and extrinsic factors", among them being abnormal growth, summer fat accumulation, and gonadal development. Because experience has shown that the formation of annuli in Alaskan stocks of northern pike generally coincides with or closely follows some of our sampling periods in late May (the literature indicates older northern pike form annuli as late as August [Casselman 1967, Laine et al. 1991]), a year was added to the count of annuli when "plus growth", (more than eight circuli since the last annulus) was present. In northern pike of age 6 or greater, at least eight circuli are detected between annuli.

During investigations, approximately 33,000 sets of scales were collected of which about 20,000 have been used to determine age. Cleithra, otoliths, and vertebrae were collected from a small subset of the fish from which scales were sampled. Data were annually reported to reflect the age composition of the respective populations. Since the start of the research, even though nine readers have been involved in the study, with seven in reading scales from T, Volkmar and George lakes, one in reading scales from Harding Lake, and one in reading the scales from Minto Flats, a single reader has been responsible for age assessment for the majority (>90%) of samples from the respective lakes for all years.

Studies of Precision

Studies of precision entailed the comparison of annuli counts in scales, vertebrae and cleithra, and the repeatability of age determination by one reader.

Comparison of Annuli Counts in Three Structures:

A scale sample; the first, second or third cervical vertebra; and a cleithrum (usually the left) were taken from a subset of the northern pike captured in Volkmar, George, and T lakes between June and August, 1986. A subsample of four fish were randomly chosen from each 100 mm length interval (starting at 0 to 99 mm, 100 to 199 mm, etc.) for a total of 40 fish, with the three structures from each fish being read three times by each of three readers. No ancillary information, such as sex and length, was provided to the readers. Readers agreed to criteria (as described in the literature above) for determining ages before the experiment began. The order of reading each structure and fish was randomly assigned. Data recorded included: reader name and number code (1 through 3); structure and code number (1 through 3); replicate number (1 through 3); date, starting time, ending time and elapsed time for each replicate reading; and annuli count and comments for each of the 40 samples for each replicate and structure. Scales were read on a microfiche reader as described above. Cleithra and vertebrae were immersed in a clearing solution (Loess solution: alcohol, glycerine, and water) and read with a dissecting microscope under direct light.

Mean ages, by reader and structure, were compared using analysis of variance (ANOVA). The experimental design was based on a general linear model with structures as fixed and readers as random effects. Multiple comparisons were made for structures and readers using Fisher's least significant difference (LSD) test ($\alpha = 0.05$ for each comparison; Peckham and Bernard 1987).

Repeatability of estimates was measured with the sampling standard error (SSE) of Sharp and Bernard (1988) and the maximum likelihood estimate (MLE) of the probability (p) of repeating an estimate. The SSE as a measure of repeatability is specific to each fish and reflects the difference in years between repeated estimates. The lower the SSE, the less the average difference between estimates. The square of the SSE was calculated as:

$$SSE^2 = \frac{\sum_{i=1}^{r} \sum_{j=1}^{n} (a_{ij} - \bar{a}_i)^2}{r\,(n - 1)} \tag{1}$$

where: a_{ij} = age of an individual fish as estimated by the ith reader on the jth replicate, n = the number of replicates (=3), and r = the number of readers (=3).

The MLE(p) is an estimate of the fraction of instances in which an estimate is repeated. With three replicates by each reader working on a single structure from a single fish, there are three possible chances for determining agreement or disagreement between pairs of estimates (three things taken two at a time). When all three readers are considered together, the probability of observing y_1 pairs of estimates in agreement from the first reader, y_2 in agreement from the second, and y_3 from the third is:

$$Prob(y_1,y_3,y_3) = \prod_{i=1}^{3} \binom{3}{y_i} p^{y_i} (1 - p)^{3-y_i} \tag{2}$$

where: p = the probability of successfully repeating an estimate. The maximum likelihood estimate of p is:

$$MLE(p) = \frac{\sum_{i=1}^{3} y_i}{9} \tag{3}$$

The MLE(p) does not reflect differences between estimates when there is disagreement; the MLE(p) only registers the presence or absence of agreement.

Repeatability with One Reader:

Another study was conducted in 1989 to determine if estimated ages from scales taken from northern pike collected in Volkmar, George and T lakes were equally repeatable, or if scales from certain populations were more difficult to read and thus would be associated with greater variation. One reader was used in the study. Thirty scales were randomly chosen from the database of each of the three populations (90 total), two non-regenerated scales per fish were processed as described above (180 scales). A scale was chosen at random and its age was determined. This was repeated for three times. The database thus consisted of 90 fish, two scales per fish, three replicates per scale, for a total of 540 estimates. The hypothesis that mean age of test subjects was the same for each replicate was analyzed with an analysis of variance with factorial treatments for each population. All effects were considered random.

The MLE(p), as described above, was calculated for all possible pairs of estimates on the same scale. The average proportion of repeated estimates from each population was also calculated.

Age Validation Using Mark-Recapture Information

Mark-recapture data (including lengths and ages as determined from scales) has been collected over several years from northern pike in T, Volkmar, George, and Harding lakes, and Minto Flats. This database contains 22,907 estimates of age belonging to 19,831 unique fish of which 1,107 fish (5.6%) were captured at least twice (Table 1A). There are some values in the database (e.g., an age of 43, annual growth of -189 mm, etc.) which are considered to be recording errors. The database was edited to remove these obvious errors in the following manner:

1) 95% confidence intervals were constructed around the mean length at age for each year and population present in the database. All observations that were outside the 95% confidence intervals were identified as potential recording errors and removed from the database for this analysis.

2) Length at time of marking was rounded off to the nearest 100 mm. For all pairs of length measurements that were taken one year apart the median annual growth was calculated for each population and 100 mm length category. Annual growth was then estimated for all pairs whose measurements were taken more than one year apart. All pairs of lengths were removed from the database if the estimated annual growth was more than 1.5 interquartiles away from the median.

For all possible pairs of age estimates that were not edited out of the database in this process, error in age determination was calculated as:

$$\text{ERROR} = \text{AGE}_{t+\Delta t} - \text{AGE}_t - \Delta t \qquad (4)$$

where:

$\text{AGE}_{t+\Delta t}$ = age assigned at later capture,
AGE_t = age assigned at earlier capture; and
Δt = the time elapsed between captures in years.

The proportion of northern pike whose difference in estimated ages reflects the time elapsed between captures was calculated for each lake as:

$$q = \frac{a}{m} \qquad (5)$$

where: a = the number of fish whose assigned ages agree with the time elapsed and m = the total number of recaptured fish in the database.

Effects of the sex of the fish, its size at recapture, and its lacustrine origin on error in determining its age were also investigated. Of the northern pike in the edited database, the sex of the fish was recorded at

Table 1A. Summary of the original, unedited northern pike database.

Lake	Number of Ages	Number of Aged Fish	Number of Fish with Multiple Captures
T	911	571	185
Volkmar	4,232	3,165	367
George	7,843	6,590	198
Harding	871	790	77
Minto	9,050	8,715	280
Total	22,907	19,831	1,107

Table 1B. Summary of edits to the northern pike database after extreme length at age was identified.

Lake	Number of Ages Removed	Number of Aged Fish	Number of Fish with Multiple Captures
T	62	513	168
Volkmar	350	2,835	318
George	684	5,910	166
Harding	79	712	60
Minto	880	7,839	230
Total	2,055	17,809	942

Table 1C. Summary of edits to the northern pike database after outlier growth was identified.

Lake	Number of Capture Pairs	Pairs Removed (Outlier Growth)	Number of Pairs in Analysis	Unique Fish in Analysis
T	275	17	258	157
Volkmar	380	67	313	258
George	170	4	166	162
Harding	60	1	59	59
Minto	246	22	224	208
Total	1,131	111	1,020	844

least once for 79% of the fish. Of the northern pike that had the sex of the fish determined several times, 21% had at least one disagreement in those determinations. Because of this difficulty in recognizing the sex of northern pike, only those fish that had the sex recorded more than once and had full agreement among recordings were used in the analysis to determine if the error distribution of male and female northern pike differ. The effect of length on accuracy in determining age was examined through simple linear regression. Because it was suspected that length was positively correlated to error rate in age determination, the length at time of recapture was used as the independent variable. The error in age determination was regressed on the length at time of recapture for all five populations.

RESULTS

Studies of Precision

Precision in age determination was examined by comparing annuli counts in three structures and repeating counts on the same structure.

Comparison of Annuli Counts in Three Structures:

Repeatability between estimates of age from all three structures was less for larger northern pike than for smaller fish (Figures 1 and 2). Repeatability for smaller fish was best for estimates from scales and worst for estimates from cleithra. Trends in MLE(p) (the probability that any two estimates of the same structure from the same fish would agree) for scales and vertebrae broke downward for fish between 400 and 499 mm FL; MLE(p) for cleithra declined gradually over fish of all sizes. The average estimated age of northern pike between 400 and 500 mm FL was just over five years. For fish in the experiment < 450 mm FL, ages estimated from vertebrae were repeated 81% of the time, 83% of the time using cleithra, and 92% of the time using scales. For fish > 450 mm TL, ages estimated from vertebrae were repeated 36% of the time, 52% of the time using cleithra, and 39% of the time using scales. When MLE(p)s were calculated for each of the three individual readers, the average proportions of repeated estimates from scales are 51%, 41%, and 24%. The average SSEs across the fish > 450 mm FL in this study are 1.00 years for vertebrae, 0.62 years for cleithra, and 0.86 years for scales. This is equivalent to saying ages estimated from vertebrae are within one year 68% of the time, ages from cleithra are within one year 89% of the time, and ages estimated from scales are within one year 75% of the time.

Average ages for northern pike as determined from scales, vertebrae, or cleithra were not significantly different for the fish in this experiment (Table 2). Average age ranged from 6.60 years from reading vertebrae to 6.19 years from reading scales. Range and general distribution of estimates among readers and fish were similar for all three structures (Figure 3). Average ages as determined by readers were significantly different, however, the maximum difference was about two-thirds of a year (Table 2).

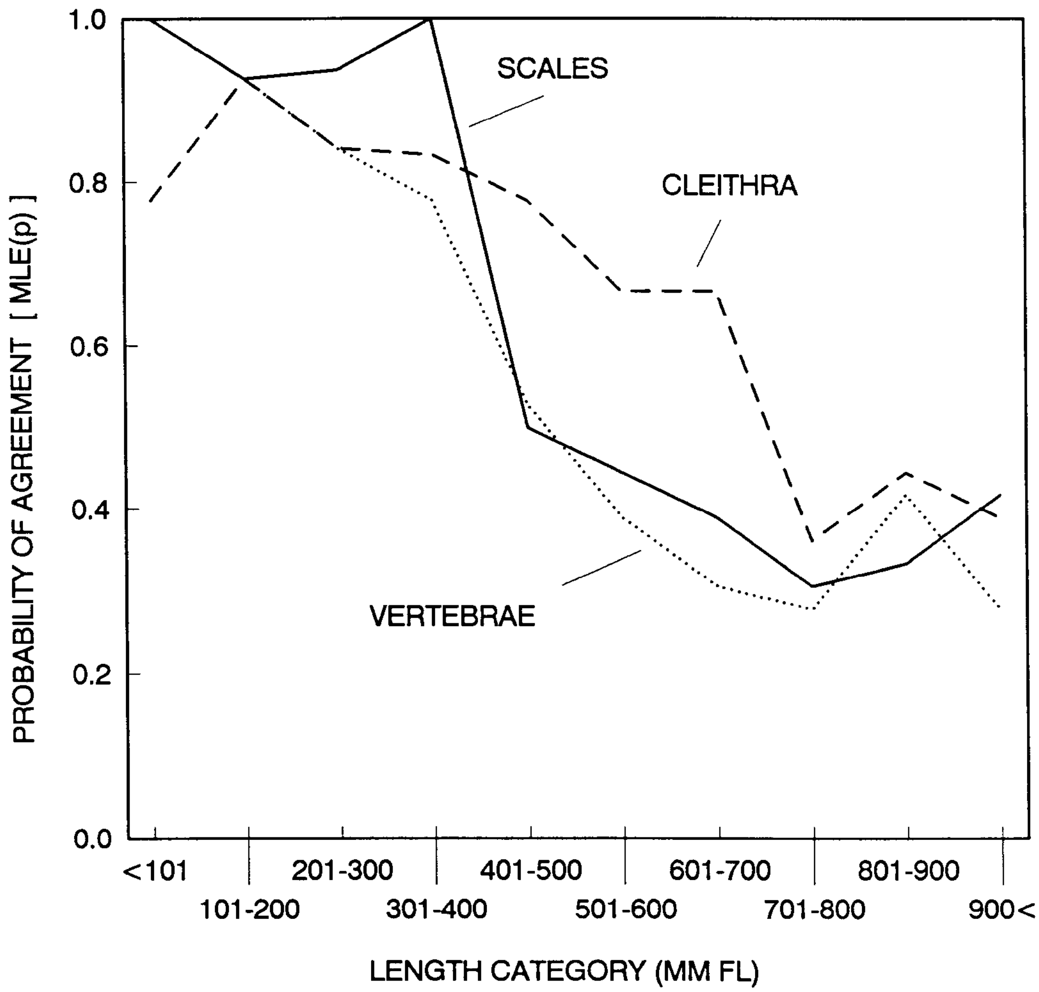

Figure 1. Repeatability of estimated ages as determined from a scale, a cleithrum, and a vertebra taken from each of 39 northern pike from George, T, and Volkmar lakes in 1986.

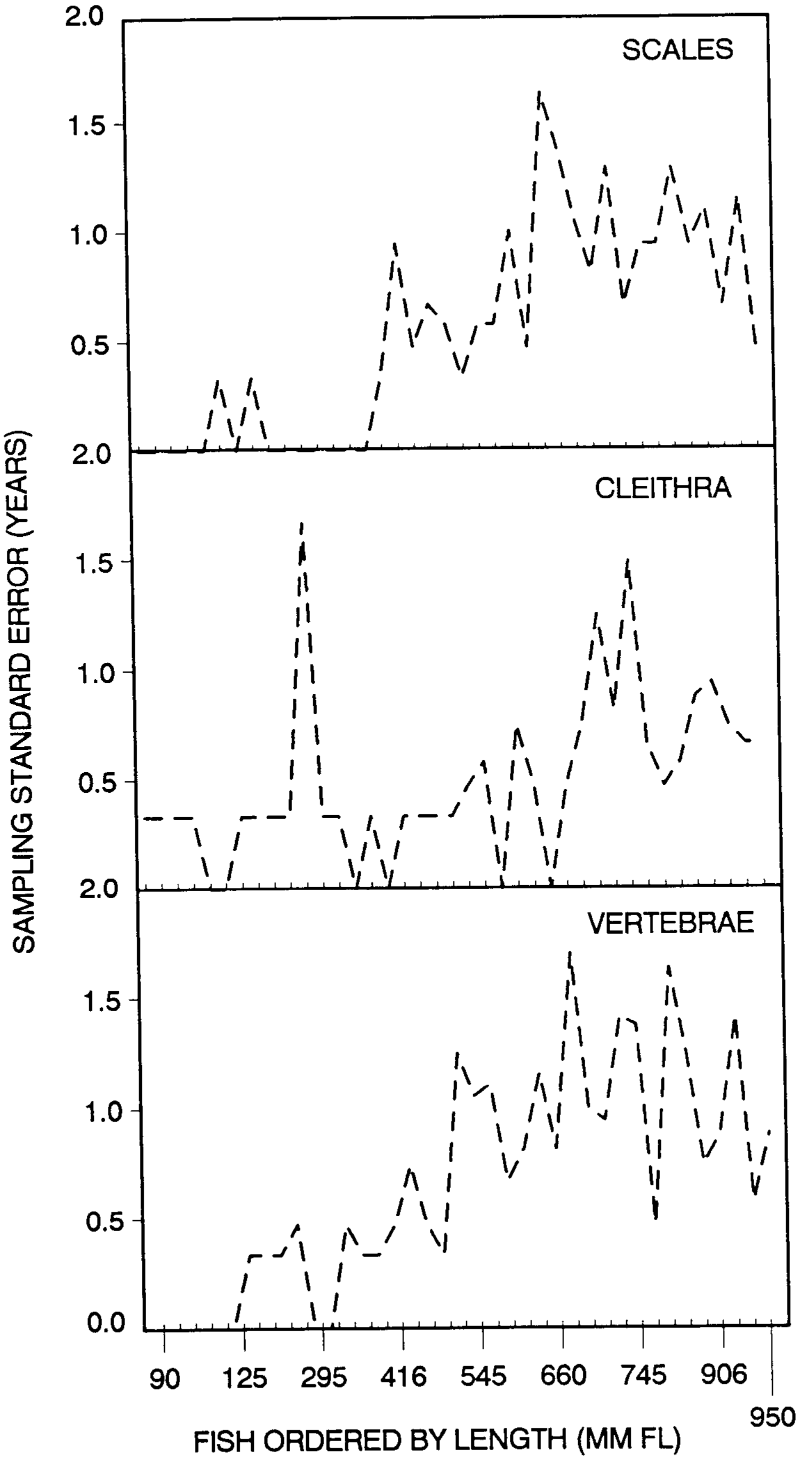

Figure 2. Average probability of repeating two estimates of age from reading a scale twice, a cleithrum twice, or a vertebra twice from northern pike of similar sizes.

Table 2. Analysis of variance table for comparison of annuli counts from vertebra, cleithra, and scales.

Source	DF	SS	MS		F	Probability
Model (M)	350	17,735	51	M/E	104.1	<0.0001
Fish (F)	38	16,854	444			
Reader (R)	2	163	81	R/RSF	39.0	<0.0001
Structure (S)	2	28	14	S/RS	1.0	0.4465
RS	4	56	14	RS/RSF	6.7	<0.0001
RSF	304	635	2			
Sampling Error (E)	585	285				
Corrected Total (T)	935	18,020				

Reader[c]	1	2	3
Mean	6.26	6.01	6.67

Structure	Vertebrae	Cleithra	Scales
Mean	6.60	6.32	6.19

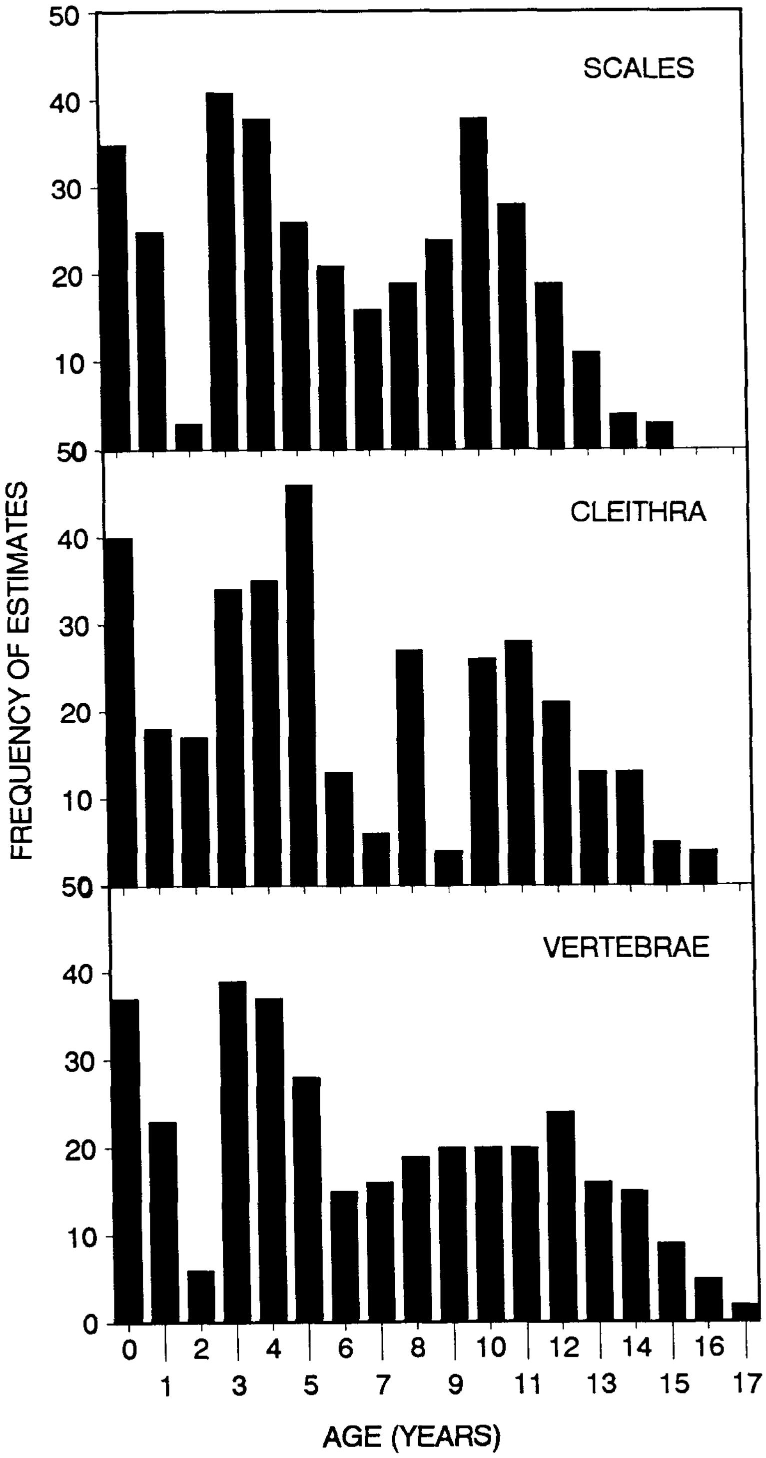

Figure 3. Age-frequency of estimated ages from scales, cleithra, and vertebrae taken from 39 northern pike collected at George, T, and Volkmar lakes in 1986.

Repeatability with One Reader:

The probability that any two estimates from the same scale agree (MLE(p)) was 0.59 for all populations and scales combined. The probability that any two estimates from the same scale agree was 0.63 for fish from T Lake, 0.44 in Volkmar Lake, and 0.70 in George Lake. The ability of the reader to repeat an estimate on a given scale decreased as the fish got larger. The probability that two estimates from the same scale agreed from fish less than 400 mm FL was 0.70 while that from fish between 400 mm and 600 mm was 0.58. The probability of two estimates from the same scale agreeing was 0.28 for fish greater than 700 mm (Figure 4).

The analyses of variance showed no significant differences among the means of the three replicate readings of the same scales from any of the three populations (all P values > 0.21; Table 3).

<u>Age Validation Using Mark-Recapture Information</u>

The edited database contained 1,020 pairs of estimated ages belonging to 844 unique fish (Table 1). Two thousand fifty-five observations (2,022 fish) were removed from the database because they were outside the 95% confidence interval for mean length at age. In addition, 111 pairs of estimates were removed because of unlikely annual growth.

The increase in the number of scale-annulus increments agreed with the time elapsed between captures 31% of the time in T Lake, 34% of the time in Volkmar Lake, 33% in George Lake, 38% in Harding Lake and 26% in Minto Flats. There was significant error for all populations (Z test, all P values < 0.001; Table 4). The error was within one year (-1, 0, +1) 72% of the time in T Lake, 72% in Volkmar Lake, 80% in George Lake, 76% in Harding Lake, and 75% in Minto Flats. The error was not normally distributed in any of the populations. The mean error, or bias, was negative in all populations except the Harding Lake population. The distribution of the error was also slightly negatively skewed in all cases except for the population in Harding Lake (Table 5).

There was a significant difference in the distribution of the error in determining the age of northern pike among all populations (χ^2 = 87.6, df = 24, P < 0.001). Further analysis showed no significant difference in the error distribution between populations from T, Volkmar, and George lakes (χ^2 = 19.9, df = 12, n = 737, P = 0.07). The error distribution for populations from Minto Flats and from Harding Lake were different from the combined error distribution for scales from populations in T, Volkmar, and George lakes (Table 5, Figure 5).

The sex of mature northern pike did not significantly influence the combined error distribution of populations from T, Volkmar and George lakes (χ^2 = 5.5, df = 5, P = 0.36; Table 6). Sample sizes were not sufficiently large enough to test for differences in the error distribution between males and females in populations from Harding Lake or from Minto Flats.

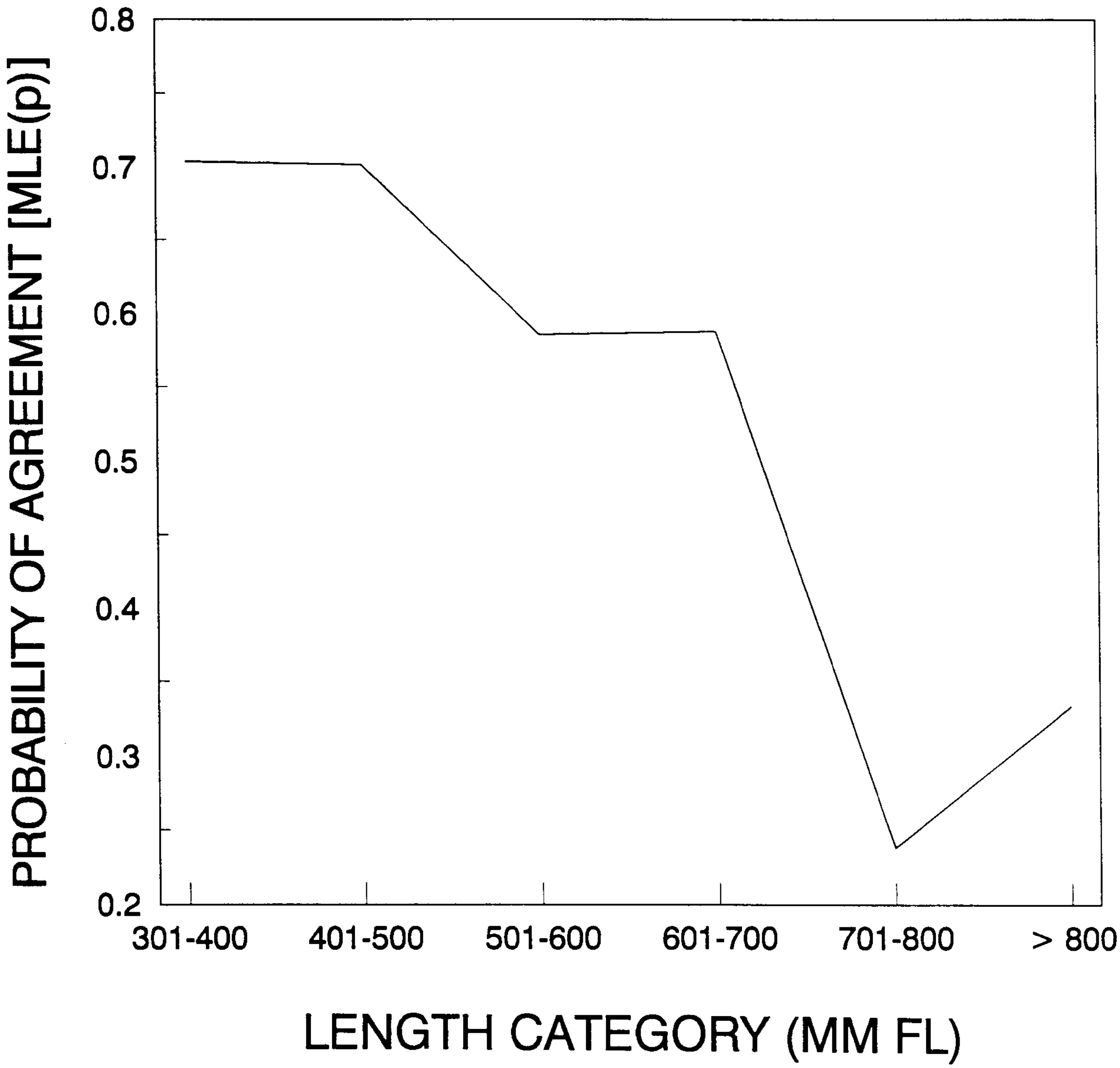

Figure 4. Average repeatability of estimated ages as determined from scales taken from 30 northern pike from George, T, and Volkmar lakes.

Table 3. Analysis of variance table for comparison of annuli counts from repeated readings.

Population	Source	DF	SS	F	P
T	fish	29	273.3		
	reading	2	0.02	0.03	0.97
	error	58	22.0		
	Total	89	295.3		
Volkmar	fish	29	248.1		
	reading	2	0.5	0.49	0.61
	error	58	27.5		
	Total	89	276.1		
George	fish	29	153.2		
	reading	2	0.6	1.59	0.21
	error	58	11.4		
	Total	89	165.2		

Table 4. Summary of the distributions of errors in determining the age of northern pike from five populations.

Population	Mean error	Standard deviation	Skewness	Z value H_o: $p = 0.5$	P
T	-0.83	1.37	-0.6	-6.1	< 0.001
Volkmar	-0.64	1.41	-0.1	-5.6	< 0.001
George	-0.36	1.25	-0.4	-4.3	< 0.001
Harding	0.21	1.28	0.4	-2.0	$= 0.023$
Minto	-0.13	1.45	-0.5	-7.2	< 0.001

Table 5. Distribution of the ERROR (in years) for pairs of estimated ages of northern pike captured and recaptured in five populations from 1985 - 1991 expressed in percentages.

	ERROR IN YEARS													
Population	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	Sample Size
T	0.4	0.4	0.4	1.9	7.0	15.9	31.0	31.0	9.7	1.6	0.4	0.4	0.0	258
Volkmar	0.0	0.3	0.6	1.0	8.0	13.1	27.5	34.2	10.5	3.2	1.0	0.3	0.3	313
George	0.0	0.0	0.0	2.4	1.8	10.8	28.3	33.1	18.7	4.2	0.6	0.0	0.0	166
Harding	0.0	0.0	0.0	0.0	0.0	10.3	14.7	38.2	23.5	8.8	2.9	1.5	0.0	68
Minto	0.0	0.0	0.9	1.3	3.6	8.9	22.8	25.9	25.9	9.8	0.4	0.4	0.0	224

Error of -7 to -3 and 3 to 5 were combined for Chi-Square analysis

H_o: Distribution of ERROR is the same among all populations $\chi^2 = 87.6$ $P < 0.001$

H_o: Distribution of ERROR is the same among populations from T, Volkmar and Harding lakes $\chi^2 = 19.9$ $P = 0.070$

H_o: Distribution of ERROR is the same between populations from Minto Flats and Harding Lake $\chi^2 = 12.4$ $P = 0.054$

H_o: Distribution of ERROR is the same between fish from Harding Lake and the combined error distribution of fish from T, Volkmar and George Lakes $\chi^2 = 29.4$ $P < 0.001$

H_o: Distribution of ERROR is the same between fish from Minto Flats and the combined error distribution of fish from T, Volkmar and George Lakes $\chi^2 = 49.9$ $P < 0.001$

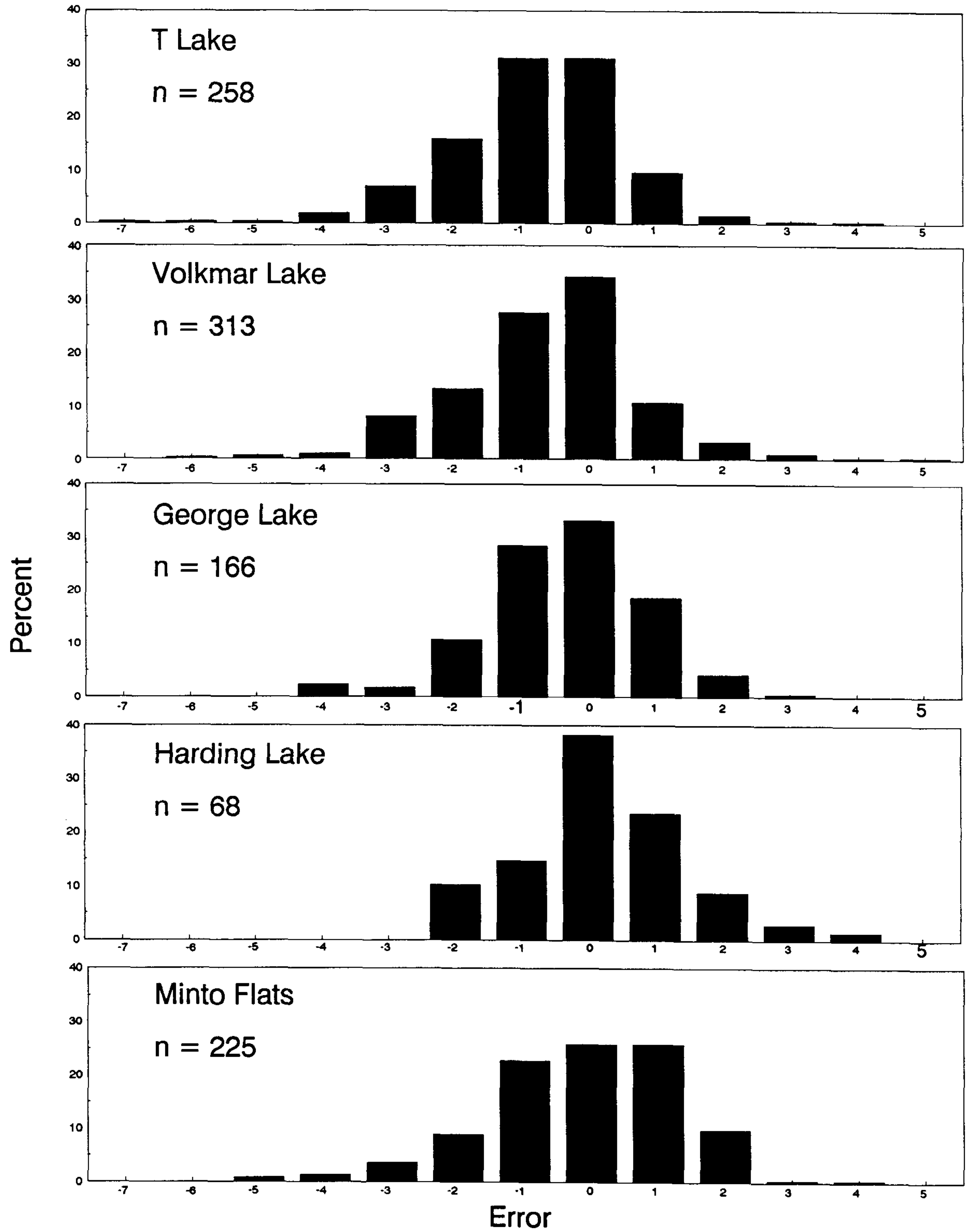

Figure 5. Error in age estimates of five populations of recaptured northern pike.

Table 6. Distribution of the ERROR (in years) for male and female northern pike from pairs of estimated ages for fish captured and recaptured.

	ERROR						
Sex	-3	-2	-1	0	1	2	Sample Size
Female	12.4	15.4	29.0	27.8	10.5	4.9	162
Male	8.0	21.6	21.6	35.2	11.4	2.3	88

H_o: error distribution is the same between sexes $\chi^2 = 5.5$ $P = 0.36$

Length had no significant effect on the error in determining the age of fish from Volkmar, George and Harding lakes. There was a negative relationship between length at recapture and error in determing the age of northern pike from T Lake and a positive relationship for fish from Minto Flats. While these relationships were statistically significant, the estimated slopes were 0.004 in T Lake and -0.002 in Minto Flats with R^2 values of 0.08 and 0.02 in T Lake and Minto Flats, respectively (Table 7, Figure 6). Length was therefore considered to not have had a biologically important impact on the error in determining the age of northern pike in this study.

DISCUSSION

The probability of repeating two age estimates from the same scale was lower than expected, and is considerably below repeatability reported elsewhere. One possible reason for low repeatability found in this study is that annuli on scales from northern pike in Alaska are more difficult to recognize than are annuli on scales collected elsewhere. The northern pike scales collected for this study were difficult to read. They were characterized by irregular growth, frequent occurrences of false annular checks, and the formation of an indistinct annulus at the end of the first year of growth. Laine et al. (1991) noted that "scales and cleithra from Squeers Lake northern pike exhibited a clear pattern of growth zones", which was definitely not the case in the scales we examined.

Another possible reason for low repeatability in this study is that personnel were not adequately trained in determining age from scales of northern pike.

Poor repeatability may account for some of the error in correctly estimating the age of a recaptured fish. In the repeatability study with one reader, the probability of any two estimates agreeing was 0.59 for all populations combined, which is slightly better than a 50:50 chance. Use of different readers in determining the age of northern pike scales could have also contributed to error in estimating the age of a fish.

Another possible source of error in correctly assigning the age of a fish could be the criteria used in determining annulus formation. The time of annulus formation was found to be significantly correlated with age in the populations of northern pike studied by Cassleman (1967), Laine et al. (1991) and Williams (1955). The older the fish, the later the annual date of annulus formation. Immature northern pike formed annuli in late spring to early summer; mature fish formed annuli as late as August, following a late April spawning event. Cassleman (1979, 1983) determined that northern pike (averaging 400 mm FL) deposited checks and translucent zones associated with annuli near the time of spawning in late April, when body and scale growth was slowest. Most rapid scale growth occurred during early summer (late April to mid-June), and coincided with lake temperatures optimum for growth (19-21 C). To minimize error in the assignment of age, Cassleman (1978, 1979) developed extensive criteria that describe the number of annuli present, the condition of the outside edge of the scale following the last annulus (plus-growth of circuli), and documented the time of annulus formation for all age-groups specific to the population studied. Both Williams (1955) and Casselman (1967)

Table 7. Analysis of ERROR regressed on length in mm at time of recapture.

Population	Regression Coefficient	t Value H_o: β=0	P	R^2	Sample Size
T	-0.004	-4.66	< 0.01	0.08	257
Volkmar	-0.001	-0.79	0.43	0.00	307
George	-0.001	-1.01	0.31	0.01	165
Harding	0.001	0.21	0.83	0.00	68
Minto	0.002	2.19	0.03	0.02	218

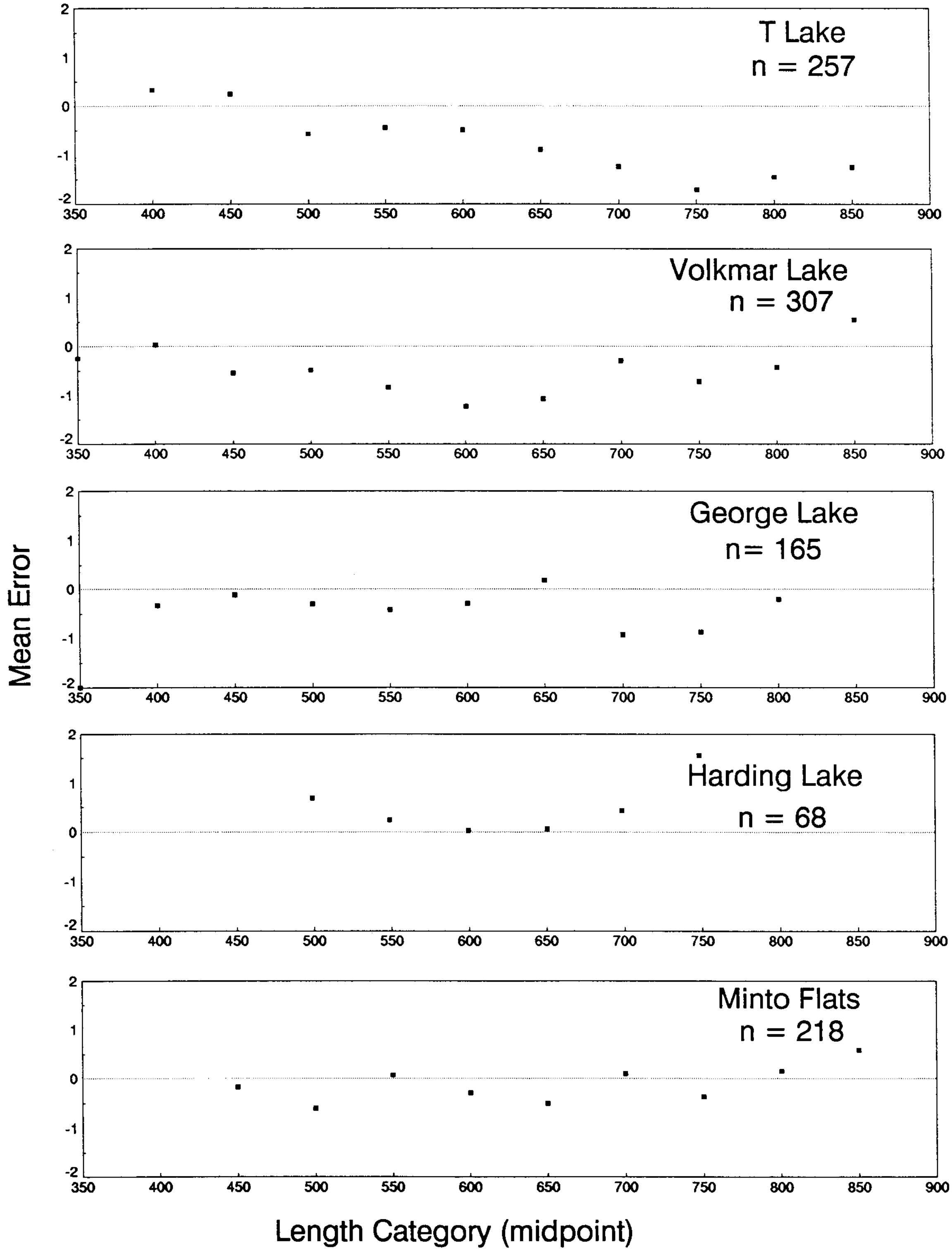

Figure 6. Mean error in age estimates of five populations of recaptured northern pike.

provided more limited but similar criteria for correctly detecting annular marks in scales from other populations of northern pike.

As noted above, Laine et al. (1991) detected a trend of delayed annulus formation by age for northern pike up to and including age 11. They had difficulty in interpreting the edge of the scale, particularly with older, slower-growing males. It was unclear if the narrow band of translucent material on the outside edge of the scale had been formed in a prior year or during the current year. Sampling recaptured northern pike from April to September enabled them to document the timing of annulus formation.

In assigning ages to northern pike scales, we assumed that annulus formation in Alaskan northern pike coincided with, or soon followed, the spawning event in mid-May. Depending upon the population, and the time of year samples were taken (the majority were obtained immediately after spawning in the lakes studied), varying degrees of plus growth after the formation of the last annulus have been noted. We assumed annulus formation was imminent, and therefore assigned another year to the estimated age when the number of circuli after the last annulus exceeded 8. Not consistently assigning an additional annulus in either the mark or recapture event could be a source of the error.

We have developed estimates of annual survival and recruitment based upon cohort analysis (Pearse 1991). Error in estimation of age is assumed to not have compromised these point estimates because the error in age determination was normally distributed. However, the variation in the estimates of recruitment and survival has probably been underestimated because they did not account for the error found in age determination of northern pike scales. Other methods of estimating population dynamics of northern pike, such as tag or length-based models, should be examined.

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